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Engineering Space Mission Support at Los Alamos National Laboratory

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- **Dave Clark**, Los Alamos Laboratory Fellow, Actinide Chemist
- **Ed Fenimore**, Los Alamos Laboratory Fellow, Astrophysicist

This talk focuses on engineering space mission support at Los Alamos National Laboratory (LANL).

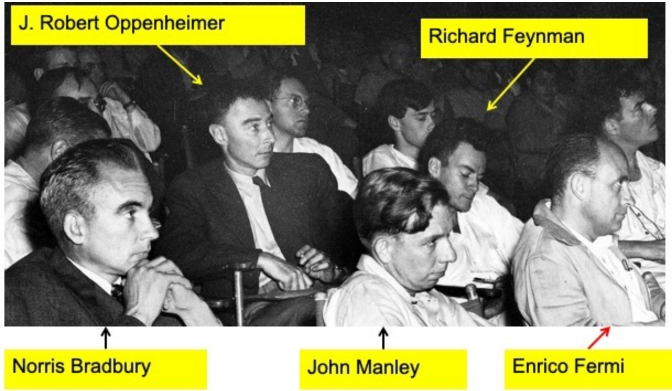
- In many cases, LANL is one of many participants on a particular space mission.
- There are many other space activities at institutions and government agencies worldwide, some of which are closely related to the ones describe in this talk.

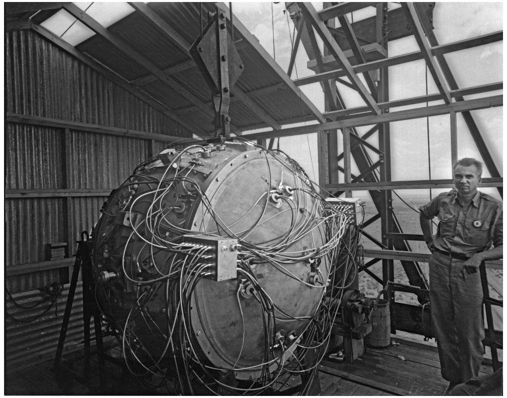
Dave Clark

Ed Fenimore

Los Alamos National Laboratory

Most people think of the **Manhattan Project (1943-1945) – not our space-related activities**





Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory

- Los Alamos National Laboratory continues to be the design laboratory for the majority of the U.S. nuclear deterrent.
- There are space-related engineering issues with these systems – this talk will <u>not</u> address these topics.

Los Alamos National Laboratory

- Approx. 100-sq-km "campus" located in northern New Mexico @ 2300-m elevation.
- 13000+ employees, approx. 1800+ w/ Science, Eng. or Math Ph. D.s
- Approx. $3 billion annual budget

LANL's space-related activities can be categorized into four areas

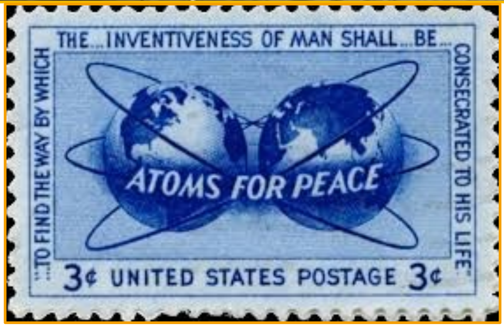
1. **Satellites and space-based instrumentation systems**
   - Monitoring various bandwidths of the electromagnetic spectrum
   - Monitoring particles
   - Focus on nuclear weapons test detection
2. **Space power systems**
   - Radioisotope heat sources
   - Radioisotope thermoelectric generators
   - Space-based nuclear power reactors
   - Nuclear-thermal rockets
3. **Analyzing and interpreting data from ground- and space-based instruments**
4. **Modeling observed physical phenomena**

As of 2014, LANL has contributed to 233 space missions

LANL has been working on space-related activities since the 1950s

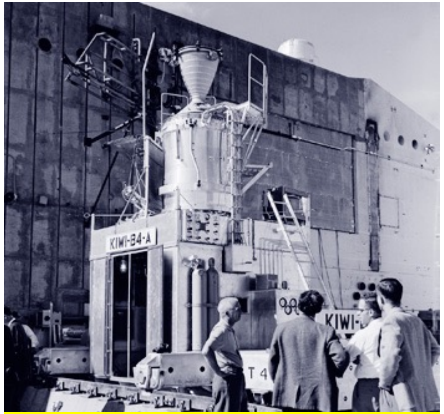
- Dec 8, 1953: US President Eisenhower described a vision for international management of atomic energy and its development for peaceful purposes.
- In 1955 US initiated 2 power programs

1. **Systems for Nuclear Auxiliary Power (SNAP) using radioisotopes and nuclear reactors for satellite electrical power**
2. **Rover, nuclear thermal rocket**



Rover/NERVA Nuclear-Thermal Rocket Engines

- Project ran from 1955 to 1973 with plans to support a Mars mission in 1979 and a permanent moon base in 1981.
- The concept used a solid graphite-core nuclear reactor to heat liquid hydrogen, which provides thrust as it expands through a nozzle.
- Three rocket engine designs were develop as part of the Rover program: *Kiwi*, *Phoebus* and *Pewee*
- Based on Rover results, NERVA focused on developing deployable rocket engines.
- Extremely high core temperature and hydrogen working fluid
  - 2683^{o}K for Kiwi-A compared to 600^{o}K for commercial power pressurize water reactor.
  - Significant materials challenges including stability, compatibility and corrosion.

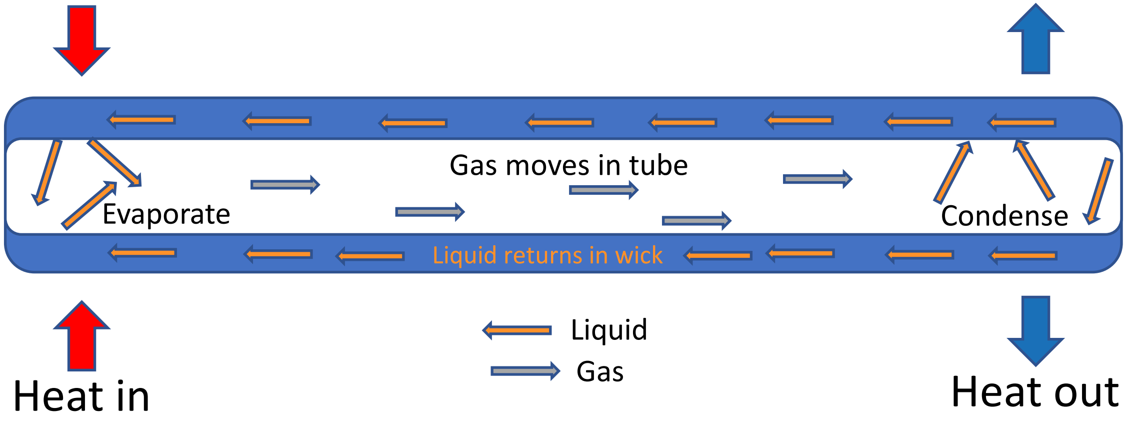


The Kiwi-B4A awaits testing at the Nevada Test Site in 1962.

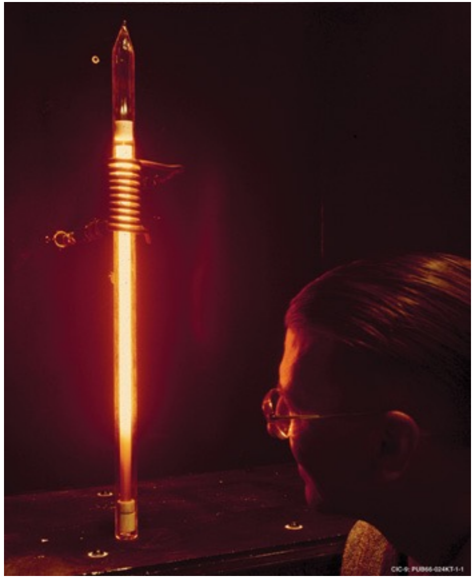
Achievements:
- 4,500 MW of thermal power
- 3,311^{o} K exhaust temperature
- 250,000 pounds of thrust
- 850 seconds of specific impulse
- 90 minutes of burn time
- Thrust-to-weight ratios of 3 to 4

Heat Pipes

- The modern capillary-based heat pipe is a heat transfer device that spun off from the Rover/NERVA program.
- Principle of operation



- Desirable for space applications: no moving parts, no power requirements , works in zero-g environments and can transport heat over long distances.

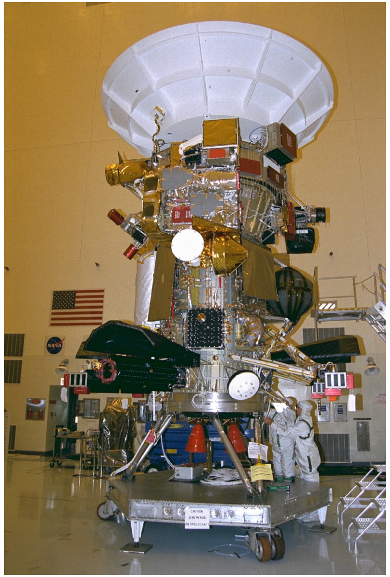


Cooling Applications:

- Electronics on geostationary satellites
- CPUs on laptops
- Foundations on the Alaska pipeline

Space Power: Radioisotope Power Systems

- Radioisotope Power Systems (RPS), thermal and electric, have played a significant role in space exploration.
  - Radioisotope Heat Sources (RHU)
  - Radioisotope Thermoelectric Generators (RTG)
- All U.S. RPSs launched to date use Pu-238
- The key advantages of RPSs include:
  - Operate continuously, do not require sunlight
  - Long life, high reliability
  - Ability to operate in hostile environments
  - Robust with predictable performance
  - Compact/Scalable
  - Provide electricity & heat for spacecraft



Cassini Space Craft: 333 LANL RPS

- 117 RHUs (310 g) heat for spacecraft components
- 216 PuO_2 pellets (33 kg) electrical power

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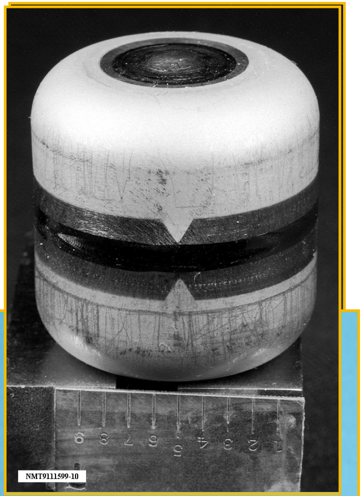
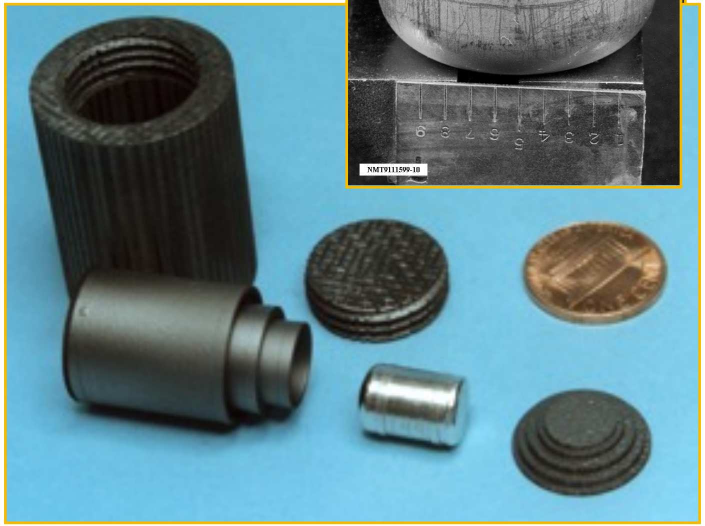
Radioisotope Power Sources

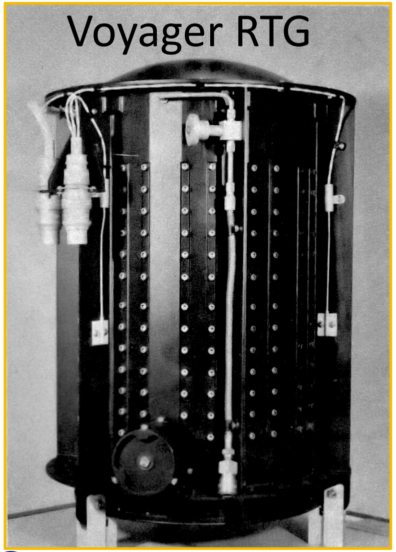
- General Purpose Heat Source (GPHS) Fueled Clad (FC)
  - Contains 151g PuO_2 sintered pellet
  - Iridium cladding with vent
  - Produces ~ $60W_{thermal}$
  - Assembled into electric generators at Idaho National Lab
- Light Weight Radioisotope Heating Unit (LWRHU)
  - Contains 2.65g PuO_2
  - Pt-30Rh cladding
  - Produces $1W_{thermal}$
  - Assembled into graphite aero shell at LANL
- **New modular heat sources are designed to keep fuel contained and immobilized during accident scenarios!**

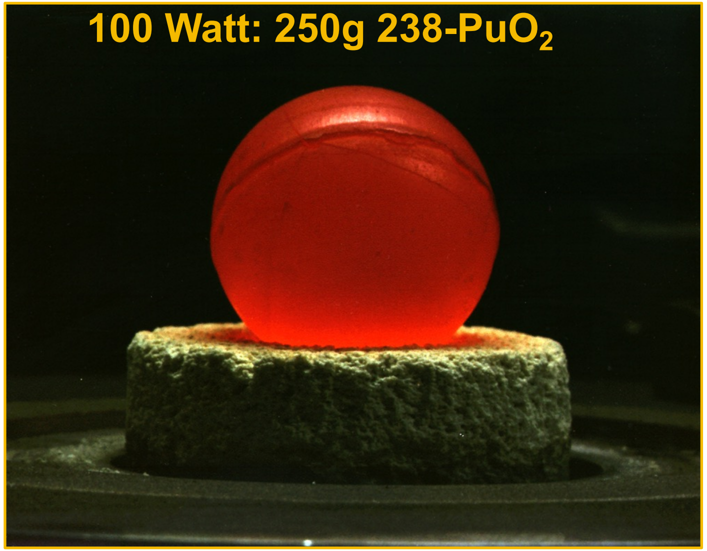


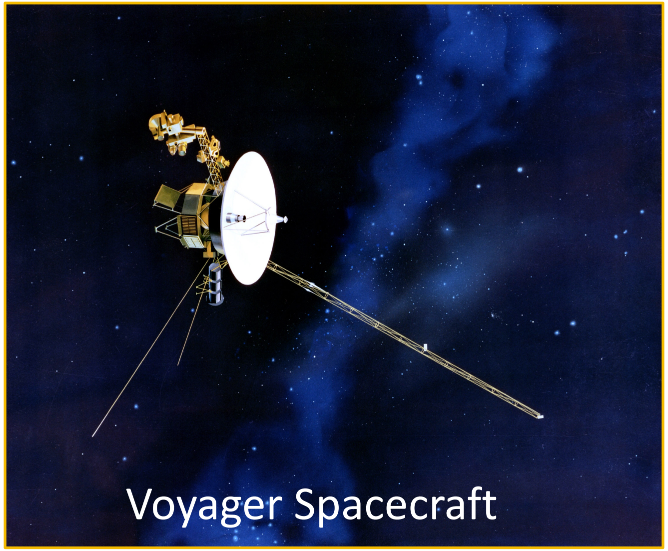


Powering Deep Space Missions

- Voyager 1 and 2 (launched Aug and Sept 1977)
  - Contains 250g PuO_2 sintered pellets
  - 3 MHW RTGs provide 475 $W_{electric}$
  - **Voyager still functioning after 4 decades in space**

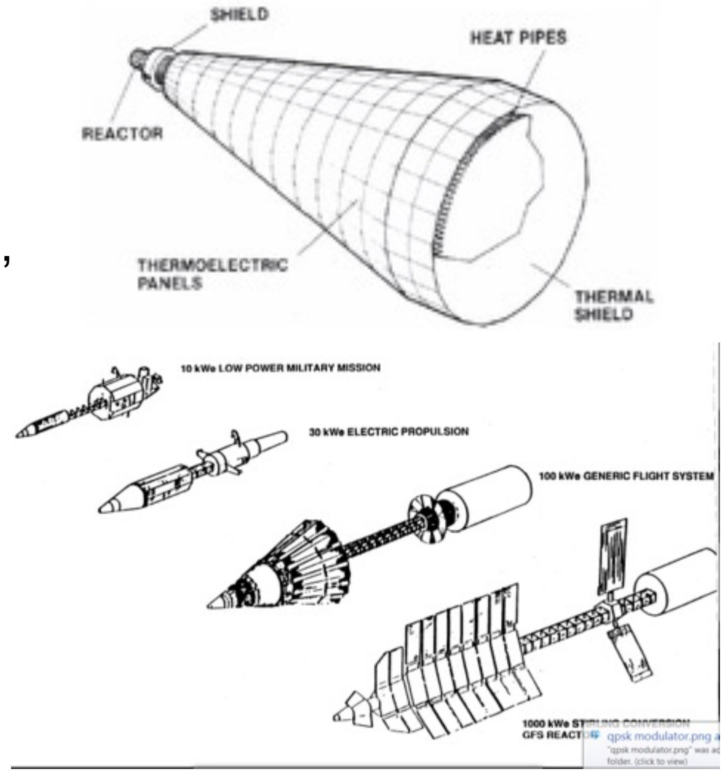






Space Power: SP-100 Reactor

- **S**pace reactor **P**rototype (SP-100) originated as part of the Strategic Defense Initiative and a collaboration between DoD, DoE and NASA
- Program (1983-1994) to develop a small, flexible, multi-mission fission power system for spacecraft and surface power for lunar and Martian exploration.
- Designed with a scalable power range of 10's-100's $kW_{electric}$
- The reactor design used heat pipes to transfer energy to thermionic electric converts

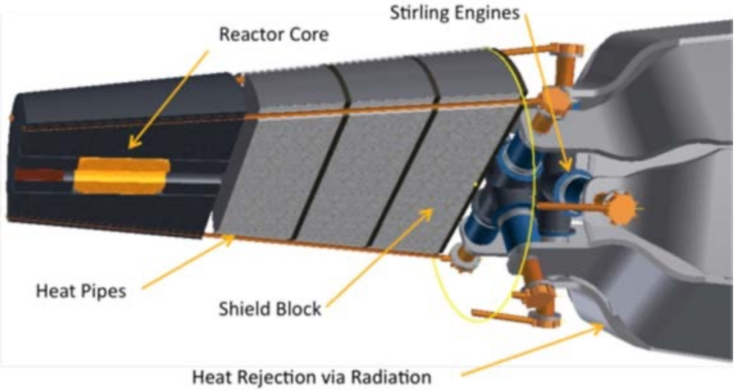


SP-100 Reactor Configurations

Space Power: KRUSTY Reactor Supporting Planetary Exploration

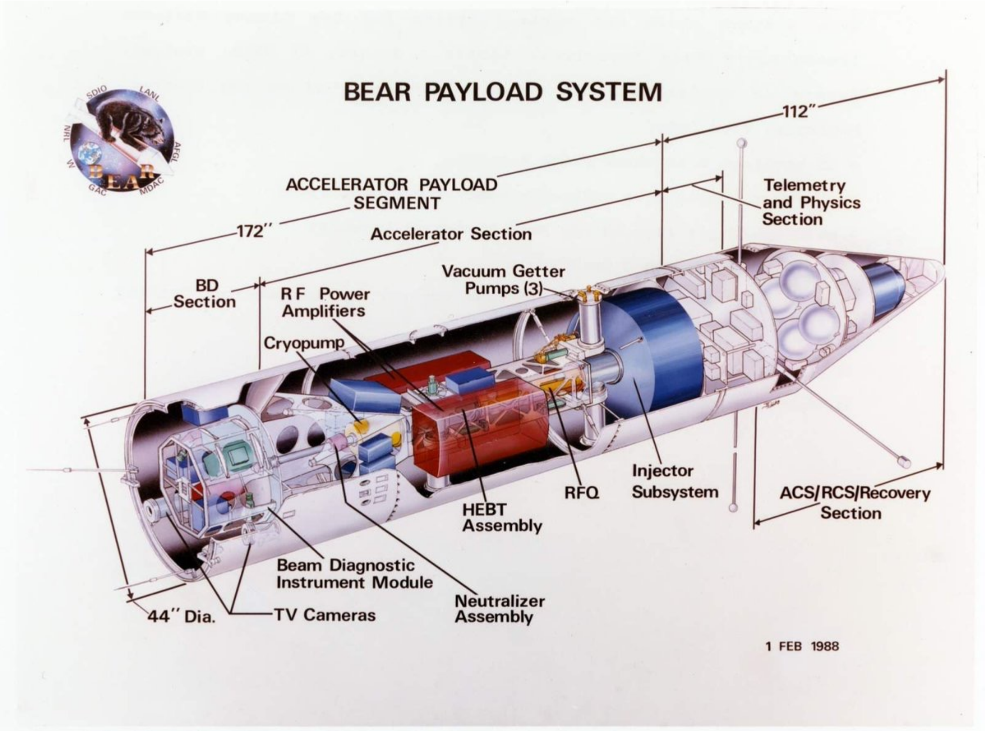
- **K**ilowatt **R**eactor **U**sing **S**terling **T**echnolog**Y** (KRUSTY)
- Collaboration between LANL and NASA
- Fission reactor designed to deliver between 1 and 10 $kW_{electric}$ of safe, reliable low-cost and compact power for 12-15 years with applications to lunar and planetary exploration.
- Liquid sodium heat pipes transfer reactor core heat to Sterling engines that drive electric generators.
- Prototype was tested in 2017-2018. These tests were the U.S.'s first ground test of a space reactor since the SNAP program in 1965.

Artist conception of KRUSTY reactor deployed on Mars



Beam Experiment Aboard Rocket (BEAR)

- Strategic Defense Initiative Project
- Launched from White Sands Missile Range July, 1989 to altitude of 200 Km
- **First time a neutral particle beam was fired in space**
- 10 mA, 1 MeV neutral hydrogen beam fired in 50-ms pulses at 5 Hz.
- The accelerator was recovered and continued to operate.



Space Instrumentation: Vela Satellites

- **Mission: Nuclear Test Ban Treaty Verification**.
  - Ten days after the 1963 Partial Test Ban Treaty went into effect, the first two of twelve Vela Satellites were put into operation.
  - These Satellites carried Los Alamos-designed-and-built sensors for detecting light, x-rays, gamma rays, neutrons, electromagnetic pulses, and the natural radiation background in space.
- **Discovered Gamma Ray Bursts (the most energetic events in the universe that result from the birth of back holes)**
  - By analyzing arrival times differences of gamma signatures on different satellites with the better-timed instruments on Vela 4, the sources were identified as coming from beyond the solar system and LANL scientists announced there were cosmic gamma ray bursts (1973).

Vela Satellites

Alexis: Almost a Failure

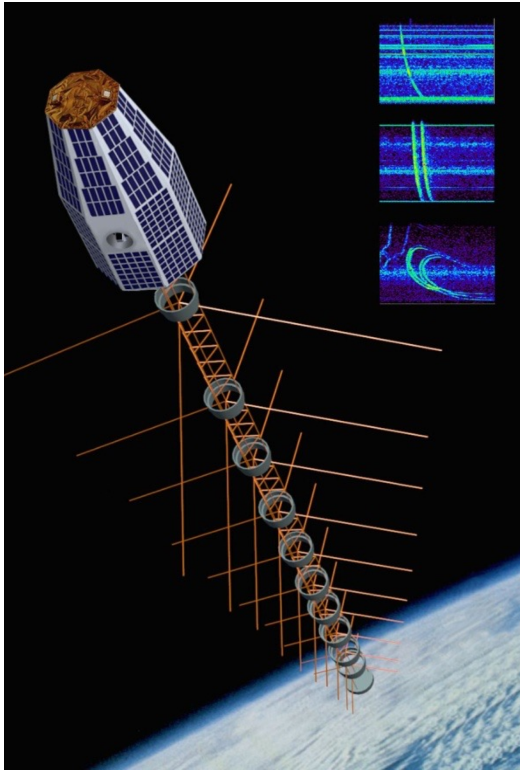
- The satellites were designed to study the ultraviolet emissions from stars and RF emissions from the earth.
- Put into orbit in 1997 from Edwards Air Force Base using a Pegasus launch vehicle.
- First satellite completely constructed at LANL.
- **Failure of a bracket on one solar panel during deployment cause communication difficulties, which took several month to overcome.**
- **Lesson learned was to not reply on a complex autonomous control systems.**

ALEXIS

Pegasus Launch Vehicle

Space Instrumentation: FORTE

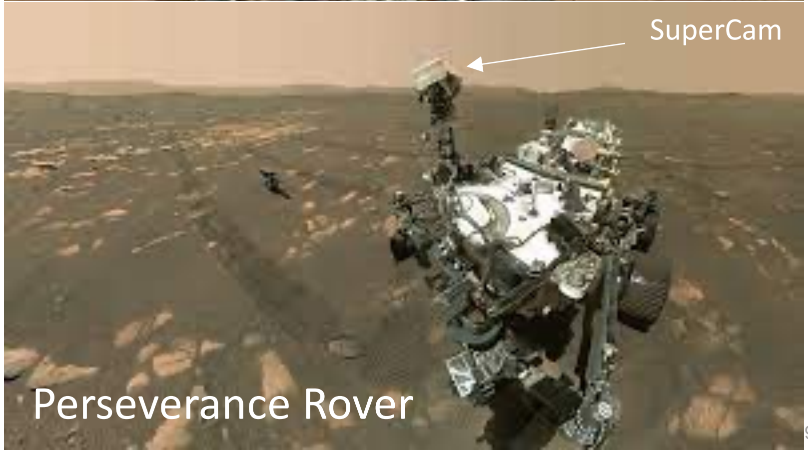
- **F**ast **O**n-orbit **R**apid recording of **T**ransient **E**vents (FORTE)
- Satellite was designed to monitor RF and optical emissions from lightning in the ionosphere.
- Onboard digital-signal-processing-based event classifier.
- Capability developed on this mission have evolved into severe weather condition monitoring systems.
- **First all composite-material spacecraft design**
- Engineering challenge: compress 10-m-long antenna into 30-cm-thick enclosure for launch



Forte Satellite

Space Instrumentation: Mars Curiosity and Perseverance Rovers

- LANL has led the development of the ChemCam (Curiosity) and SuperCam (Perseverance) laser-induced, breakdown spectroscopy instruments.
  - Laser vaporize small portion of a rock creating a hot plasma.
  - Rock composition identified through spectrum analysis of the emitted light.



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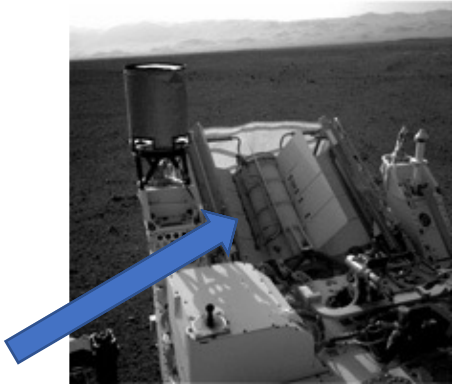
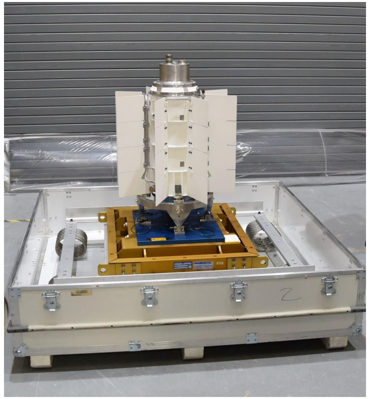
Powering the Mars Rovers

- Curiosity Rover was the first to use a Multi-Mission RTG (MMRTG) that provides 110 W electric for 11 instruments.
- Perseverance also uses MMRTGs
- Perseverance has 32 LANL radioisotope heat sources.
- MMRTGs are designed to provide power for 14 years.



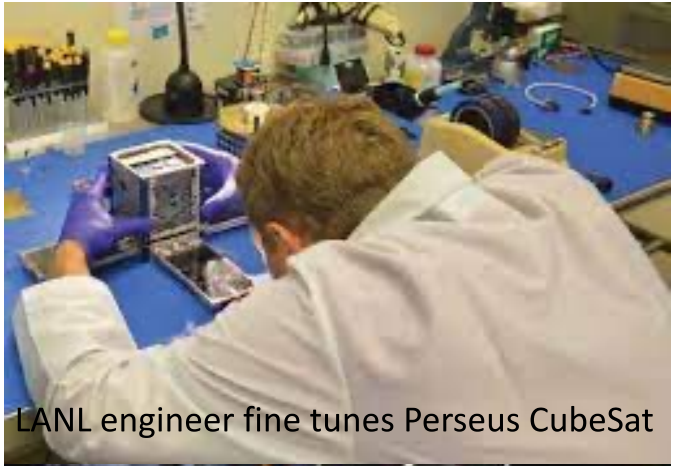
Curiosity Rover MMRTG



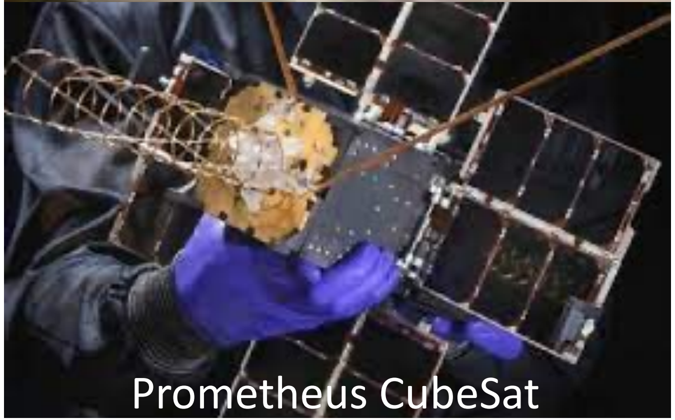
Perseverance Rover MMRTG

CubeSats

- Four Perseus (1.5 U) launched on SpaceX Faclon-9 rocket in 2010.
  - Demonstration of rapid-response satellite deployment capability.
  - Built with commercial off-the-shelf parts (replacement cost of $20K US).
  - Developed with a low-cost ($5K US) transportable ground stations.
  - In 300-km orbit for 3 weeks
- Eight Prometheus (3.0 U) went into 500-km orbit in 2013 for 3 years
  - Improved communications, more processing, more autonomous operations



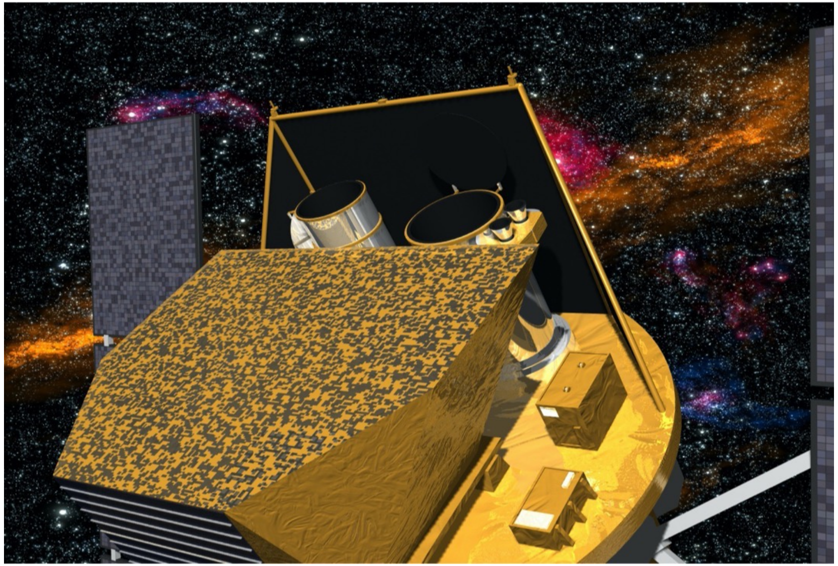
LANL engineer fine tunes Perseus CubeSat



Prometheus CubeSat

Science of Signatures for Space: Automated Gamma Ray Bursts Detection

- SWIFT Satellite launched 2004 with the mission to detect gamma-ray bursts.
- First self-tasking satellite – designed to autonomously find unusual cosmic events.
  - System decides where to image based on burst alert telescope that uses code-aperture mask consisting of 52,000 randomly place 5-mm lead tiles 1-m above a plane of 32,000+ X-ray detector tiles.
  - X-ray telescope further refines the location of the gamma-ray burst.
  - UV/Optical Telescope used after Swift has slewed toward the brust.



Software engineering is a significant part of the satellite operation and control.

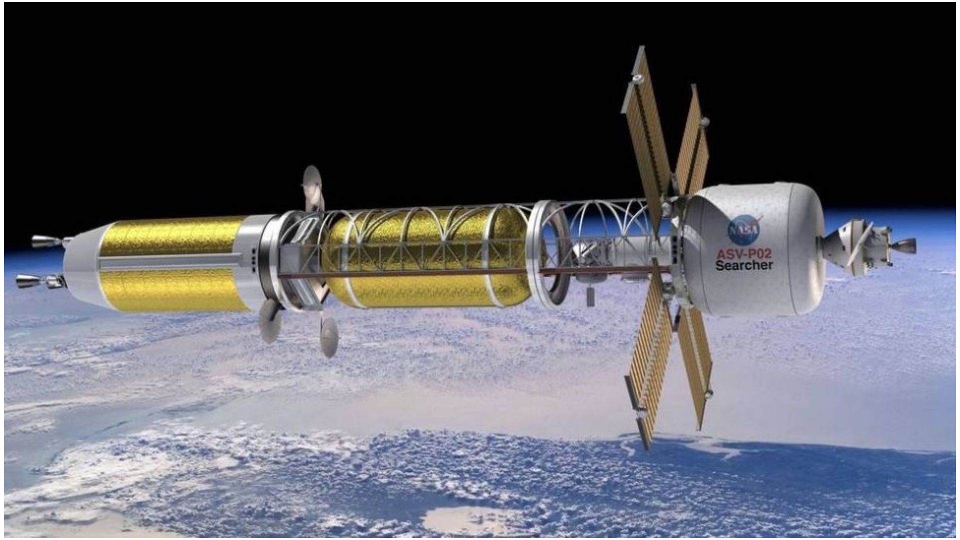
Future Activities: Searching for Life on Titan in a Nuclear-Powered Helicopter

- DOE's next Multi-Mission Radioisotope Thermoelectric Generator is set to power the *Dragonfly* rotorcraft lander (nuclear-powered, electric helicopter) that will be used to explore Saturn's largest moon, Titan.
- This mission is expected to launch in 2026, arriving on Titan in 2034.

MMRTG –powered Dragonfly Rotorcraft

Future Activities: Nuclear Thermal Space Propulsion (Remember Rover/NERVA?)

- In July, 2021 the U.S. Department of Energy and NASA funded the development of three nuclear thermal propulsion design concepts.
- Potential for 3-4 month transit time to Mars versus 9-month transit time with traditional chemical rockets



Artist Conception of a Modern Nuclear-Thermal Rocket

Engineering Challenges for Space

- Successful space missions need innovative mechanical, electrical, materials, software and nuclear engineering! Some challenge areas are:
  - **Mechanical** - Thermal Management (heating and cooling), most difficult to test on the ground
  - **Mechanical** – Shock and Vibration, make sure the system survives launch, deployment, accident scenarios, reentry and retrieval
  - **Electrical** - Radiation Hardening of Electronics, can be ground tested in specialized facilities, e.g. accelerators, test reactors, synchrotrons
  - **Electrical** – Telemetry, data transfer to iridium satellite then to earth
  - **Materials** – Corrosive materials in reactors
  - **Materials** – Widely varying operating temperatures
  - **Software** - Screen the sensor data and only sends pertinent data to ground
  - **Software** - Remote operations requires lots of pre-launch time to plan each minute of the system operation.
  - **Nuclear** – Manage decaying power availability
  - **Nuclear** – Management of radioactive decay particles (swelling caused by He^{2+})